Moment-Based Physical Models of Broadband Clutter due to Aggregations of Fish

Roger C. Gauss
Code 7144
Acoustics Division
Naval research Laboratory
Washington, DC 20375-5350
phone: 202-767-3524 e-mail: roger.gauss@nrl.navy.mil

Richard H. Love
BayouAcoustics
176 Bald Eagle Drive
Abita Springs, LA 70420
phone:985-893-0138 e-mail: rick_love@att.net

Award Numbers: N0001411WX20739 (RG), N0001411M0158 (RL)

LONG-TERM GOALS

Contribute to a new understanding of what fish parameters control mid-frequency (MF; 1-10 kHz) biological clutter, including the relative influence of oceanographic phenomena; and provide benchmark data sets and statistical models for signal-processing algorithm development. These in turn will help to develop a capability to statistically forecast the impact of bioclutter on MF Navy systems.

OBJECTIVES

Develop, and refine/validate with field data, broadband stochastic models of MF clutter due to aggregations of fish based on higher-order statistical measures describable in terms of physical and system parameters. Environmentally, these models would provide physics-based measures of acoustical uncertainty based on biological and oceanographic parameters.

APPROACH

Develop and validate a physics-based statistical modeling approach for treating MF acoustic clutter phenomena due to fish via a combination of theoretical developments and field-data collection/analysis. Knowledge on fish distributions and bioacoustics will be used to identify (and provide data on) the key physical parameters needed both to develop (and validate) the clutter models, and to quantify uncertainty.

Theoretically, we build on recent work at NRL in both clutter persistence characterization and physics-based probabilistic modeling (Fialkowski and Gauss, 2010). The characterization method estimates clutter persistence over sequential sets of pings of normalized correlator (matched-filter) output, with the goal of stabilizing/minimizing coherent propagation effects and thereby identifying the more

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **SEP 2011**	2. REPORT TYPE	3. DATES COVERED **00-00-2011 to 00-00-2011**

4. TITLE AND SUBTITLE **Moment-Based Physical Models of Broadband Clutter due to Aggregations of Fish**	5a. CONTRACT NUMBER
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)	5d. PROJECT NUMBER
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Naval research Laboratory,Acoustics Division,Code 7144,Washington,DC,20375-5350**	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR’S ACRONYM(S)
	11. SPONSOR/MONITOR’S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

significant interferers. The probabilistic model is based on NRL's three-parameter Poisson-Rayleigh model that, like the K-type model, provides a physical context for relating the characteristics of data distributions to scatterer attributes (density and relative strength). However, with its extra degree of freedom, the P-R model offers the potential to exploit more information through higher-order (4^{th} and 6^{th}) data moments, and so enhance clutter characterization. The model offers an advantage over other moment-based clutter characterization methods when deriving statistics over a relatively small range extent with correspondingly small sample distributions, such as spatially variable fish aggregations. The utility of this method is enhanced by the closed-form expressions used to estimate the P-R parameter values from data moments.

Experimentally, we build on the success of two recent ONR-sponsored experiments in the Gulf of Maine (Sept. 2010 and Sept 2011), where NRL exploited the broadband capabilities of its MF acoustic system to map out both reverberation and clutter spatially, temporally, and spectrally (Gauss et al., 2009). The 2012 Basic Research Challenge (BRC) field studies will involve two main acoustical sampling strategies: 1) regional surveys, which produce synoptic "snap-shots" of the fish aggregations, and 2) recording at fixed stations to observe the temporal evolution of the aggregations. The detection range of this NRL MF system in this application is up to 20 km, depending on acoustic propagation conditions. If available, a NOAA fisheries vessel would deploy nets to sample the fish for biological information, and use its traditional HF acoustics to characterize their depth dependence and spatial patchiness.

Investigations of fish and fish scattering are being conducted in support of both the theoretical and experimental clutter modeling efforts. Studies of fish abundances, distributions, schooling characteristics, and other parameters are being conducted to optimize the probability of suitable biological clutter being encountered on the BRC 2012 experiment. Also, models of scattering from fish schools can be considered the kernels of biological clutter modeling. There are two models covering two different scattering regimes that are being modified/upgraded. One covers the frequency regime near swimbladder resonance (Feuillade et al., 1996), and the other covers frequencies in the geometric scattering regime above resonance (Love, 1981). Both of these models may be applicable to scattering encountered during the 2012 BRC experiment, depending on fish sizes, depths and swimbladder properties.

The end result of the effort, when coupled with high-resolution short-range measurements and assessments by other BRC PIs (led by Dr. Kelly Benoit-Bird, BRC Chief Scientist), would be high-fidelity maps of distributions of swimbladder-bearing fish spatially and temporally. From oceanographic assessments, the in-situ short-range data, and bioacoustic assessments, the key physical parameters needed for the statistical clutter models (and so clutter-reduction algorithm development) will be determined semi-empirically.

WORK COMPLETED

This year primarily focused on preparing for the summer 2012 cruise. Additionally, we began our model developments.

2012 cruise preparation

Work began on identifying the fish species to be encountered on the BRC 2012 west-coast experiment, and determining their spatiotemporal characteristics. Based on this work, an experimental operations

area (OPAREA) was selected for which to conduct our 2012 acoustic measurements (Fig. 1). We conducted a broad examination of the present status of fish stocks over a wide region off northern California, Oregon and Washington in order to choose species having the highest potential for a successful fish scattering experiment. This process was based on several factors for all species. They are, in a more or less prioritized order: (a) abundance and geographical distribution; (b) seasonal distribution; (c) ease of locating the stock; (d) ease of ensonifying aggregations of fish with NRL's acoustic systems; (e) non-proximity to ocean boundaries; (f) correspondence of the operating frequencies of NRL's acoustic systems to the near swimbladder resonance and geometric fish scattering regimes for which scattering models exist; (g) changes in fish depths or aggregation properties from day to night; and (h) similarity of species to those that might be expected to be important in tactically significant operational areas. It was determined that hake and sardines will be the primary species of interest (Hill et al., 2010; Stewart et al., 2011; Nero et al., 1998). Accordingly, we began a detailed study to determine pertinent scattering-related characteristics of the chosen species.

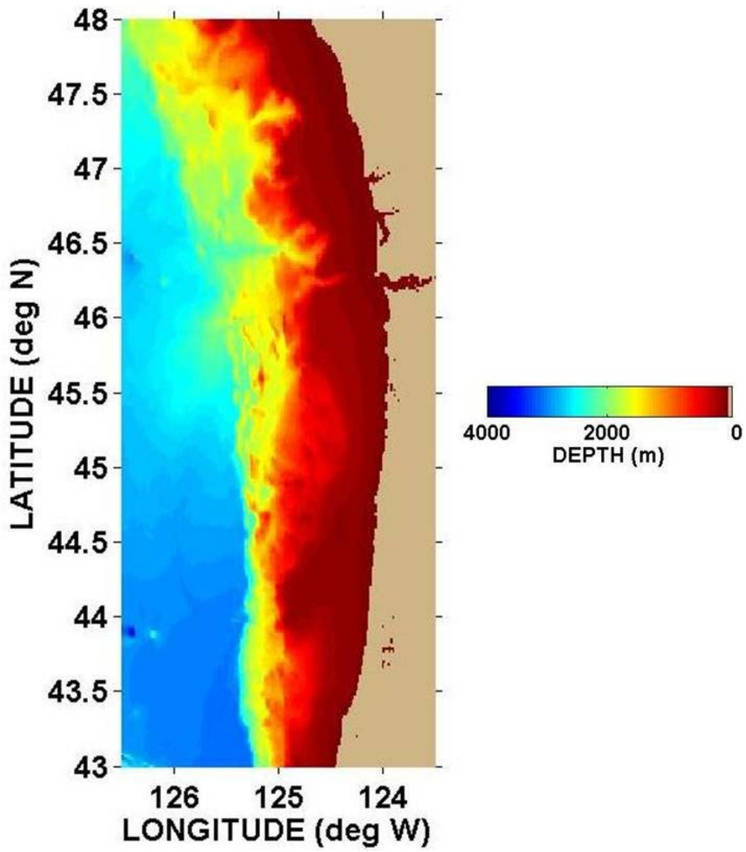

Fig.1. Identified primary 2012 experimental operating area (characterized by NGDC 1-min-resolution bathymetry).

Clutter modeling

Work began on extending NRL's Poisson-Rayleigh (P-R) statistical model (Fialkowski and Gauss, 2010) to more realistically account for scatterer properties. The P-R model provides a physical context

for relating the characteristics of data distributions to scatterer attributes (density and relative strength). Given the non-uniform spatial nature of bottom and biologic features, the corresponding acoustic clutter is non-uniform. In statistics, the variance-to-mean ratio (VMR) provides a normalized measure of the dispersion of a probability distribution. Clustered, concentrated data are over-dispersed, which statistically corresponds to a VMR > 1. Since for a Poisson distribution, VMR = 1, the Poisson component of the P-R model needs to be generalized to handle this more typical 'over-dispersed' data case. Accordingly, candidate generalized distributions that can better account for these statistically significant deviations have begun to be evaluated. The most promising of those examined to date is the Conway-Maxwell-Poisson (CMP) distribution which can not only handle over- and under-dispersed data, but is a member of the exponential family, which has many favorable properties.

Since it expected that scattering from fish schools during the west coast experiment will most likely be in the geometric scattering regime, work began on refining the geometric scattering model. The present model was primarily based on data collected on anchovy schools. It uses 6 classes of fish spacings, 9 classes of school sizes, and 37 ensonified aspects to develop target strength distributions for different species of fish. It includes multiple scattering and absorption. It also accounts for the effects of beam width and pulse length. Much has been learned about fish spacings and school sizes since this model was developed. The model is being upgraded based on this newer general knowledge about schooling and to take advantage of today's computing power. Data specific to sardines schools are also being obtained for input to the model so that it will be directly applicable to the expected experimental scenario.

RESULTS

Based on archival fishery and climatological information, identified the primary OPAREA for the location and time of year of the 2012 at-sea experiment, and the primary fish species to generate MF reveberation and clutter (dispersed hake and schooling sardines).

IMPACT/APPLICATIONS

Echoes from fish can be the dominant source of reverberation (over the seafloor and sea surface) over a range of important conditions including operational "look" angles, operational frequencies, and operational bandwidths. Reverberation can mask low-to-mid-SNR targets. Moreover, fish echoes often retain coherent structure (i.e., survive the normalization process used by operational Navy active sonars). Coupled with their inherent spatiotemporal variability, fish can be both a significant clutter problem and a prime source of acoustical uncertainty for active sonars. The results of this effort will advance our understanding of those fish characteristics responsible for sonar clutter, and in turn, will provide improved clutter models for synthetic trainers, improved clutter management techniques for active clutter discrimination and classification, and improved sonar system performance prediction.

RELATED PROJECTS

Gauss is a participant on a PEO C4I & Space (PMW 120; Marcus Speckhahn) committee to help develop a new shallow-water volume scattering strength (VSS) database and a real-time, geo-referenced VSS mapping procedure. Gauss is also on the ONR 322OA (Robert Headrick) Applied Reverberation Modeling Board (ARM-B) whose charter it is to understand the limitations/major challenges presented by today's and tomorrow's active sonars relative to reverberation and clutter predictive capabilities, and recommend solutions (the way ahead). The focus of both these efforts is on

MF active monostatic sonars. Both of these positions allow Gauss to identify and act on technology insertion points. Additionally, Gauss has in transition to CNMOC's Oceanographic and Atmospheric Master Library (OAML) the first Navy-standard Fish Scattering Strength (FSS) algorithm. The planned, semi-empirical acoustic uncertainty estimates could serve as a basis of FSS upgrades. Under a 6.2 NRL-Base project, Gauss has been developing moment-based clutter-rejection techniques for improving automated active Navy classifiers that will be under evaluation for transition to the ACB AN/SQQ-89 A(V) 15 system in FY12-14 under the ONR Active Sonar Automation Enabling Capability Project (Keith Davidson). Gauss is also working with NUWC (Wendy Petersen—potential 2012 BRC cruise participant) regarding providing bioclutter data as a potential upgrade to the Characterization and Reduction of Active False Tracks (CRAFT) database.

REFERENCES

Feuillade, C., R.W. Nero, and R.H. Love, "A low frequency acoustic scattering model for small schools of fish," J. Acoust. Soc. Am. **99**, 196-208 (1996).

Fialkowski, J.M., and R.C. Gauss, "Methods for Identifying and Controlling Sonar Clutter," IEEE J. Ocean. Engr. **35**, 330-354 (2010).

Gauss, R.C., J.M. Fialkowski, E.L. Kunz, R. Menis, T.K. Stanton, C.J. Sellers, and J.M. Jech, "Clutter Variability due to Fish Aggregations: Mid-Frequency Measurements in the Gulf of Maine," in *Proceedings of The 3rd International Conference & Exhibition on "Underwater Acoustic Measurements: Technologies and Results"*, ed. J.S. Papadakis and L. Bjørnø, 21-26 June 2009, Nafplion, Peloponnese, Greece (F.O.R.T.H., Hellas, Greece, 2009), pp. 459-466.

Hill, K.T., N.C.H. Lo, B.J. Macewicz, P.R. Crone, and R. Felix-Uraga, "Assessment of the Pacific sardine resource in 2010 for U.S. Management in 2011," National Marine Fisheries Service, La Jolla, CA, NOAA-TM-NMFS-SWFSC-469.(2010).

Love, R.H., "A model for estimating distributions of fish school target strengths," Deep-Sea Res. **28A**, 705-725 (1981).

Nero, R.W., C.H. Thompson, and R.H. Love, "Low-frequency acoustic measurements of Pacific hake, *Merluccius productus*, off the west coast of the United States," Fish. Bull. **96**, 329-343 (1998).

Stewart, I.J, R.E. Forrest, C. Grandin, O.S. Hamel, A.C. Hicks, S.J.D. Martell, and I.G. Taylor, "Status of the Pacific Hake (Whiting) Stock in U.S. and Canadian Waters in 2011," Pacific Fishery Management Council, Portland, OR (2011).